B_s^0 mixing and lifetime difference measurements at CDF

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Abstract. We review latest experimental results on the B_s mixing and lifetime difference measurements at CDF. We report on the latest β_s and $\Delta\Gamma_s$ results from $B_s \to J/\psi\phi$. We also discuss flavor specific $\Delta\Gamma_s$ measurements, including information from hadronic channels, $B_s \to D_s D_s$ and $B_s \to KK$. We describe the new flavor tagging methodology and its calibration using the B_s oscillations.

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B_s MESON PHYSICS

The time evolution of a mixture of the B_s^0 and its antiparticle $\overline{B_s^0}$ is described by the Schrodinger equation $i\frac{d}{dt}\begin{pmatrix} B_s^0(t) \\ \overline{B_s^0}(t) \end{pmatrix} = \left(M - i\frac{\Gamma}{2}\right)\begin{pmatrix} B_s^0(t) \\ \overline{B_s^0}(t) \end{pmatrix}$, where M and Γ are the 2×2 mass and decay matrices that relate the flavor eigenstates, B_s^0 and $\overline{B_s^0}$, with the mass eigenstates, B_s^H and B_s^L. The difference in mass and width between B_s^H and B_s^L is related to the off diagonal elements of the mass and decay matrices as follows: $\Delta m_s = m_H - m_L \sim 2|M_{12}|$ and $\Delta\Gamma = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|cos\phi_s$, where $\phi_s = arg(-M_{12}/\Gamma_{12})$ is the CP phase and $\phi_s \sim 0.04$ in the standard model. The fact that the mass eigenstates are not the same as the flavour states gives rise to oscillations between the B_s^0 and $\overline{B_s^0}$ states with a frequency proportional to the mass difference of the mass eigenstates Δm_s.

MEASUREMENTS OF $\Delta\Gamma_s$ AND CP VIOLATION PHASE $\beta_s^{J/\psi\phi}$

While Δm_s has been measured to great precision, $\Delta\Gamma_s$ has so far been measured imprecisely. To proceed with a measurement of $\Delta\Gamma_s$ one assumption is generally made: that the B_s^0 light mass eigenstate is CP even and the heavy state is CP odd. With this assumption, two approaches to measuring $\Delta\Gamma_s$ are pursued. The first is to analyse $B_s^0 \to J\psi\phi$ decays, fitting the angular distributions between the decay products in order to decipher the CP odd and even content. The second is to measure the lifetime in a CP specific decay for which the proportion of CP odd and even states is known a priori.

Flavor Specific measurement: $B_s^0 \to D_s^+ D_s^-$

The decay $B_s^0 \to D_s^+ D_s^-$ is a $b \to c\bar{c}s$ decay with purely CP even composition. Therefore a lifetime measurement of $B_s^0 \to D_s^+ D_s^-$ would measure Γ_L. Moreover, the branching ratio of the $B_s^0 \to D_s^+ D_s^-$ mode provides an indirect measurement of the difference in width between the two weak eigenstates through the relation $\Delta\Gamma_s/\Gamma_s = 2 \times Br(B_s^0 \to D_s^+ D_s^-)$ [1]. CDF, using $355 pb^{-1}$ integrated luminosity, measured the $B_s^0 \to D_s^+ D_s^-$ ($D_s^\pm \to \phi\pi^\pm$ or K^*K or $\pi\pi\pi$) branching ratio relative to that of $B^0 \to D_s^+ D^-$ [2]:

$$\frac{B_s \to D_s^+ D_s^-}{B^0 \to D_s^+ D^-} = 1.44^{+0.38}_{-0.31}(stat)^{+0.08}_{-0.12}(syst) \pm 0.21(\frac{f_s}{f_d}) \pm 0.20(BR(\phi\pi)). \qquad (1)$$

From this measurement, a 95% confidence level limit of $\Delta\Gamma_s/\Gamma_s \geq 0.012$ was set. At CDF, we are currently exploiting a new Neural Network based selection strategy to update the $\Delta\Gamma_s/\Gamma_s$ measurement in the $B_s^0 \to D_s^+ D_s^-$ decay. In 1.6 fb^{-1}, the new selection yields ~ 105 $B_s^0 \to D_s^+ D_s^-$ and ~ 1930 $B^0 \to D_s^+ D^-$ events respectively. In Figure 1 we show the fit to the invariant mass for the $B_s^0 \to D_s^+ D_s^-$ ($D_s^\pm \to \phi\pi^\pm$) and $B^0 \to D_s^+ D^-$ ($D^+ \to k\pi\pi$, $D_s^\pm \to \phi\pi^\pm$) events, respectively.

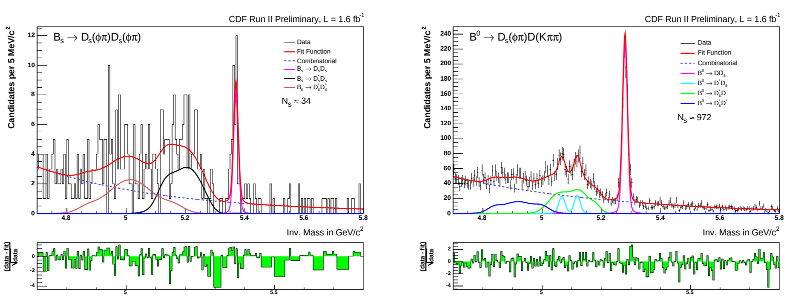

FIGURE 1. Fit to the invariant mass of $B_s^0 \to D_s^+ D_s^-$ ($D_s^\pm \to \phi\pi^\pm$) candidates (left) and $B^0 \to D_s^+ D^-$ ($D^+ \to k\pi\pi$, $D_s^\pm \to \phi\pi^\pm$) candidates (right).

Flavor Specific measurement: $B_s^0 \to K^+ K^-$

The decay $B_s^o \to K^+ K^-$ is $\sim 95\%$ CP even and therefore a lifetime measurement in this state can be combined with knowledge of average B_s^0 lifetime in order to obtain an indirect measurement of $\Delta\Gamma_s$. The CDF II detector collects and reconstructs significant samples of B^0 and B_s^0 charmless two body decays. In particular, using a data sample of $360 pb^{-1}$, CDF measured the $B_s^o \to K^+ K^-$ lifetime to be $\tau(B_s^0 \to K^+ K^-) = 1.53 \pm 0.18\ (stat) \pm 0.02\ (syst)\ ps$. Combining the CDF measurement of $B_s^0 \to K^+ K^-$ lifetime with HFAG average B_s^0 lifetime in flavor specific decays $\tau(B_s^0) = 1.454 \pm 0.040\ ps$, CDF measured $\Delta\Gamma_s/\Delta\Gamma_s(B_s^0 \to K^+ K^-) = -0.08 \pm 0.23\ (stat) \pm 0.03\ (syst)$.

$\Delta\Gamma_s$ in $B_s^0 \to J/\psi\phi$ and CP Violation Phase $\beta_s^{J/\psi\phi}$

The study of $B_s^0 \to J/\psi\phi$ decays ($J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$) allows the searching for CP non-conservation beyond the Standard Model (SM). In these decays CP violation occurs through the interference between the decay amplitudes with and without mixing. In the SM the relative phase between the decay amplitudes with and without mixing is $\beta_s^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$ and it is expected to be very small [3]. New physics contributions manifested in the B_s^0 mixing amplitude may alter this mixing phase by a quantity ϕ_s^{NP} leading to an observed mixing phase $2\beta_s^{J/\psi\phi} = 2\beta_s^{SM} - \phi_s^{NP}$. Large values of the observed $\beta_s^{J/\psi\phi}$ would be an indication of physics beyond the SM [1]. The decay $B_s^0 \to J/\psi\phi$ is a physics rich decay mode as it can be used to measure the B_s^0 lifetime, decay width difference $\Delta\Gamma_s$ and the CP violation phase $\beta_s^{J/\psi\phi}$. While the B_s^0 meson has spin 0, the final state J/ψ and ϕ have spin 1. Consequently, the total angular momentum in the final state can be either 0,1 or 2. States with angular momentum 0 and 2 are CP even while the state with angular momentum 1 is CP odd. Angular distribution of the final muons and kaons from J/ψ and ϕ decays can be used to separete the CP eigenstates. There are three angles that completely define the directions of the four particles in the final state. We use the angles $\vec{\rho} = \{\cos\theta_T, \phi_T, \cos\psi_T\}$ defined in the transversity basis introduced in [4]. At CDF, using 2.8 fb^{-1} integrated luminosity, an unbinned maximum likelihood fit is performed to extract the parameters of interest, $\beta_s^{J/\psi\phi}$ and $\Delta\Gamma_s$. CDF reconstructs a signal sample of ~ 3200 events using a Neural Network based selection. The measured B_s^0 lifetime and decay width difference are $\tau(B_s^0) = 1.53 \pm 0.04(stat) \pm 0.01(syst)$ ps and $\Delta\Gamma = 0.02 \pm 0.05(stat) \pm 0.01(syst)$ ps^{-1}. An exact symmetry is present in the signal probability distribution which is invariant under the simultaneous transformation ($2\beta_s \to \pi - 2\beta_s$, $\Delta\Gamma \to -\Delta\Gamma$, $\delta_{||} \to 2\pi - \delta_{||}$, and $\delta_\perp \to pi - \delta_\perp$). This causes the likelihood function to have two minima. Confidence regions in the $\beta_s^{J/\psi\phi} - \Delta\Gamma$ plane are constructed by CDF, Figure 2 (left). The resulting regions show the expected double minimum structure and are shifted with respect to the SM expectation. The significances of the deviation is 1.8 standard deviations. Combina-

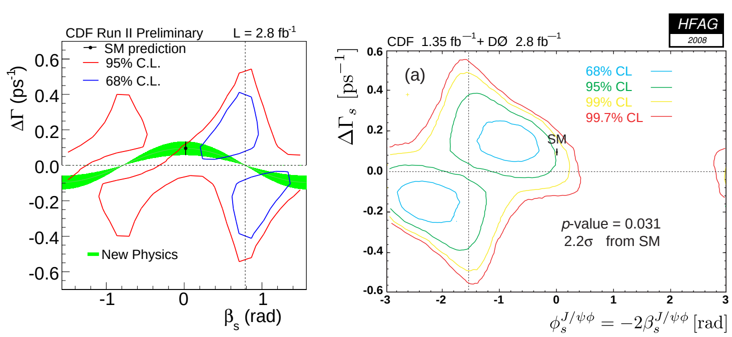

FIGURE 2. Confidence regions in the $\beta_s^{J/\psi\phi} - \Delta\Gamma$ plane from CDF (left). Confidence regions in the $\phi_s - \Delta\Gamma$ plane corresponding to the combined CDF and D0 datasets (right)

tion of the CDF and D0 results has been performed [5]. The combination includes the D0 analysis with 2.8 fb^{-1} [6] and a previous CDF result [7] that used only 1.35 fb^{-1} of

data. Confidence regions, shown in Figure 2 (right), result in a 2.2σ deviation of $\beta_s^{J/\psi\phi}$ from the SM. Although the combined deviation from the SM expectation is not statistically significant, the independent CDF and D0 fluctuations in the same direction are interesting to follow in the future as the analyzes will be updated using more data. By the end of the Tevatron running, samples of 8 fb^{-1} are expected. A joint effort of the CDF and D0 is currently underway to produce Tevatron combined confidence regions in the $\Delta\Gamma_s - \beta_s$ plan. Two approaches are pursued: the first combines the bi-dimensional profile likelihoods of the two experiments, a preliminary result can be found in [8]; the second approach, more powerful but on a longer time scale, will perform a simultaneous fit of the CDF and D0 data.

MEASUREMENT OF B_s MIXING AND FLAVOR TAGGING

CDF observed B_s^0 mixing and measured $\Delta m_s = 17.77 \pm 0.12\ ps^{-1}$ with remarkable precision [9]. Good sensitivity to Δm_s can be exploited to calibrate improved flavor tagging algorithms. At CDF, a new flavor tagging algorithm is under development. The new approach combines the information of alla the tracks in the event. For a given B_s candidate, tracks are divided in three categories: 1) tracks in the same side in wich the B_s was found; 2) tracks that are an electron or muon candidate; 3) all remaining tracks. For each category, a track flavor correlation neural network is trained; finally, the output of the track flavor correlation neural networks are combined in a likelihood ratio. The new flavor tagger is currently calibrated and checked on Monte Carlo samples and on a new B_s^0 mixing measurement. The new flavor tagger will be used in the flavor tagged CP Violation Phase $\beta_s^{J/\psi\phi}$ analysis.

REFERENCES

1. I. Dunietz et al. *Phys.Rev. D* **63**, 114015 (2001).
2. T. Aaltonen et al. (CDF Collaboration), *Phys. Rev. Lett.* **100**, 021803 (2008).
3. I. I. Y. Bigi, A. I. Sanda, *Nucl. Phys.* **B193**, 85 (1981).
4. A. S. Dighe, I. Dunietz, R. Fleischerde, *Eur. Phys. Rev. J. C* **6**, 647 (1999).
5. E. Barberio et al., *Heavy Flavor Averaging Group*, 2007 http://www.slac.stanford.edu/xorg/hfag.
6. V. Abazov et al. (D0 Collaboration), *Phys. Rev. Lett.* **101**, 241801 (2008).
7. T. Aaltonen et al. (CDF Collaboration), *Phys. Rev. Lett.* **100**, 121802 (2008).
8. http://www-cdf.fnal.gov/physics/new/bottom/090721.blessed-betas_combination2.8/
9. A. Abulencia et al. (CDF Collaboration), *Phys.Rev.Lett.* **97**, 062003 (2006).